Curing PCCP in California Heat

Michael I. Darter, Ph.D., P.E.

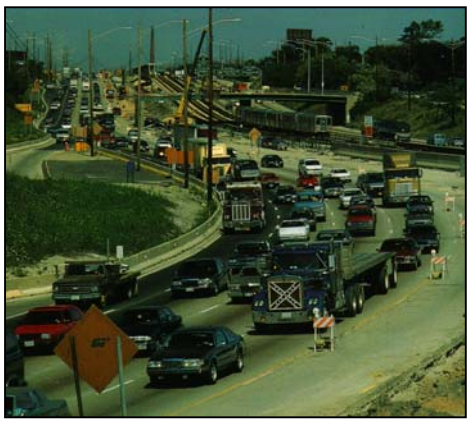
Chetana Rao, Ph.D

APPLIED RESEARCH ASSOCIATES, INC.

An Employee-Owned Company

Should we change paving operations based on

“Weather Conditions?”



Climatic factors to be considered in paving operations

- Hot weather
- Cold weather
- Relative humidity
- Wind speed
- Sunshine
- Base material

Critical!!

How mix design and construction methods can interact with the weather conditions

Curing – Most common means of controlling effects of weather

- The maintenance of a satisfactory **moisture content** and **temperature** in concrete during its **early ages** to **enhance** hydration and hardening of the concrete slab
  - Curing blanket
    - Water retention cover such as burlap
  - Curing compounds
    - Liquid surface coating
    - Pigmented to reflect light

    (reduce absorption of solar radiation)

Critical!!

Supplements good mix design and construction

Curing Is More Beneficial Than You Think!

- Commonly Known Benefits of Curing
  - Controls moisture loss from top of slab surface
  - Improves strength gain and durability of surface
  - Prevents plastic shrinkage cracking
  - Lowers permeability of surface
  - Prevents Freeze-Thaw damage
  - Resistance to chemical attack

Poor Curing Is Bad(er) Than You Think!

- Lack of curing results in bad things
  - Low strength of surface (higher abrasion)
  - High shrinkage at top of slab
  - Plastic shrinkage cracking likely
  - Potential for scaling, spalling (low entrained air)
  - Built-in temperature gradient-top down cracking
  - Higher surface shrinkage-top down cracking

Curing Is More Beneficial Than You Think!

- Additional Moisture Impact
  - Reduces shrinkage of surface and moisture gradient through slab
- Additional Temperature Impact
  - Reduces temperature at surface
  - Controls built-in temperature gradient at construction
  - Affects Joint openings at cooler temperatures over time

Curing

- Proper curing is management of temperature & moisture
- A good mix requires two conditions for proper hydration and strength gain:
  - Adequate moisture for hydration
  - Optimum temperature management for hydration
    - Reaction rate doubles for every 10 deg Celsius increase in temperature

	Moisture	Temperature
Low	No hydration – low strength gain	No hydration
High	Excessive shrinkage, durability problems	Excessive shrinkage and low long term strength

Curing Compound Application – Good Practice

Keep close to placing operation. Apply very early.

Curing Compound – Good practice

Reach all exposed areas

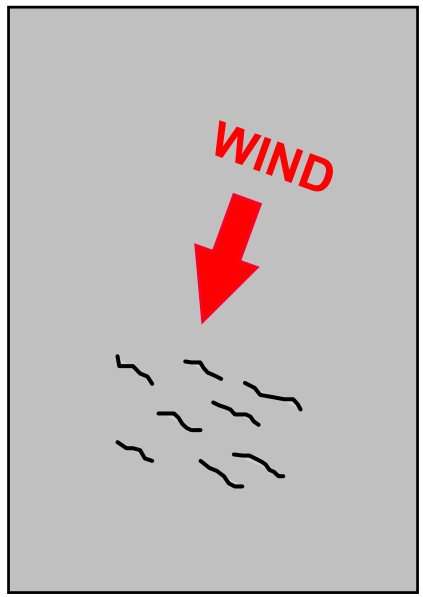
Curing Compound – Poor practice

Plastic Shrinkage Cracking

- Primary cause: rapid surface moisture evaporation
- Factors:
  - Air temperature
  - Relative humidity
  - Wind velocity
  - Concrete temperature
- Potential greater when Tconcrete > Tair

Plastic Shrinkage Cracks

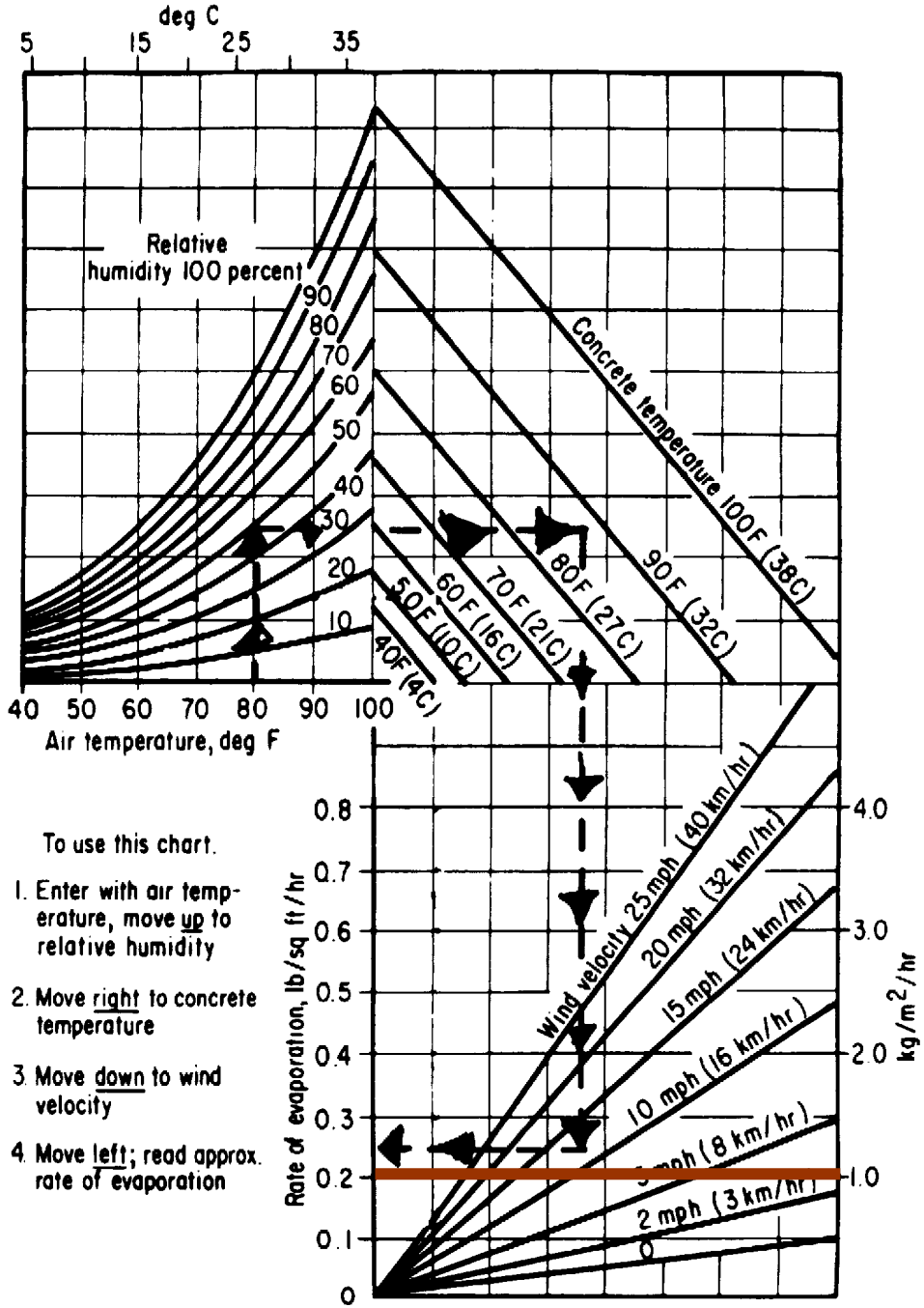
- 0.3-0.6 m long
- Parallel
- Partially penetrate depth
- Usually tight



Plastic Shrinkage Cracking

Rate of Evaporation Chart: Critical Conditions

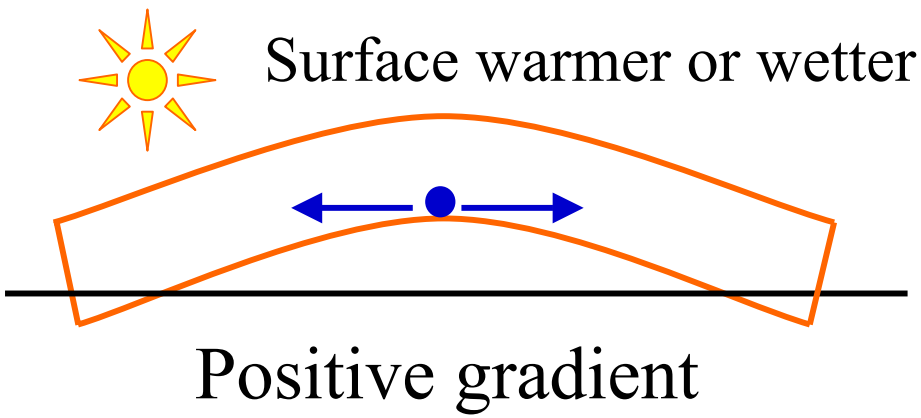
- Function of air temperature, Relative humidity, Concrete temperature, Wind velocity
- Controls plastic shrinkage when rate of evaporation is less than 1 kg/m^2/hr
- The higher the evaporation rate, the higher the RISK
- Note: this chart does not consider curing compound

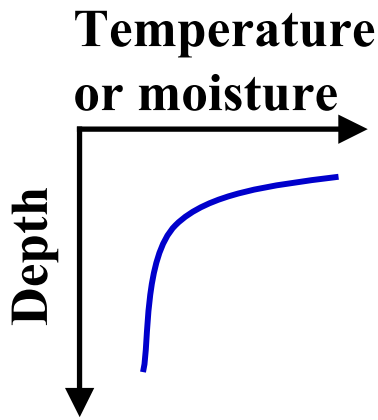


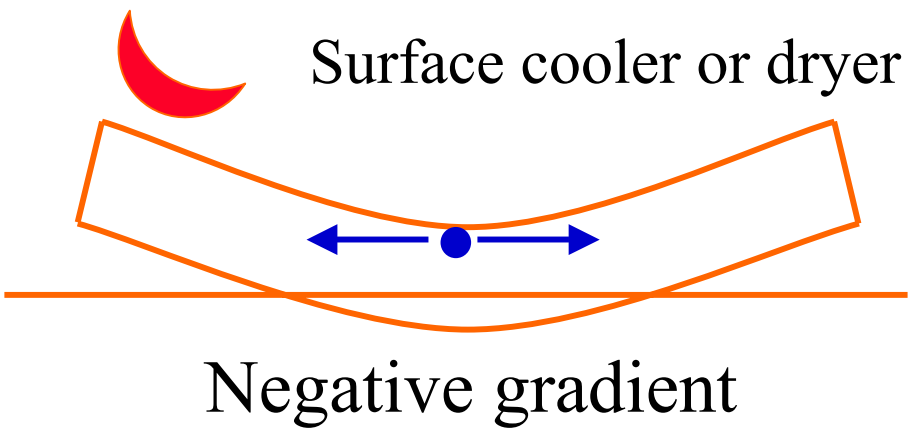
Caltrans "Wind Days"

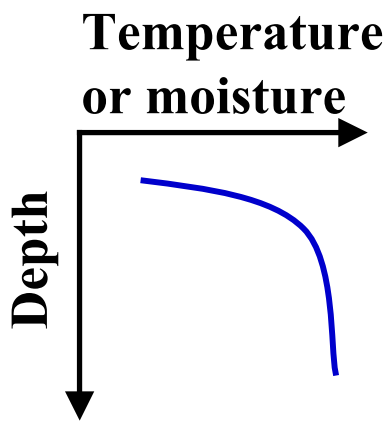
- If wind, humidity, and temperature are such that rate of evaporation would be too high, plastic shrinkage cracking is probable, unless extraordinary construction procedures were used.
- **Good Option**: If very unfavorable paving conditions may exist, where the probably of plastic shrinkage cracking is likely,
  - then provide contractor "wind days" where paving is not allowed, but then
  - "wind days" are added at the end of the contract.

Slab Curling & Warping Concept

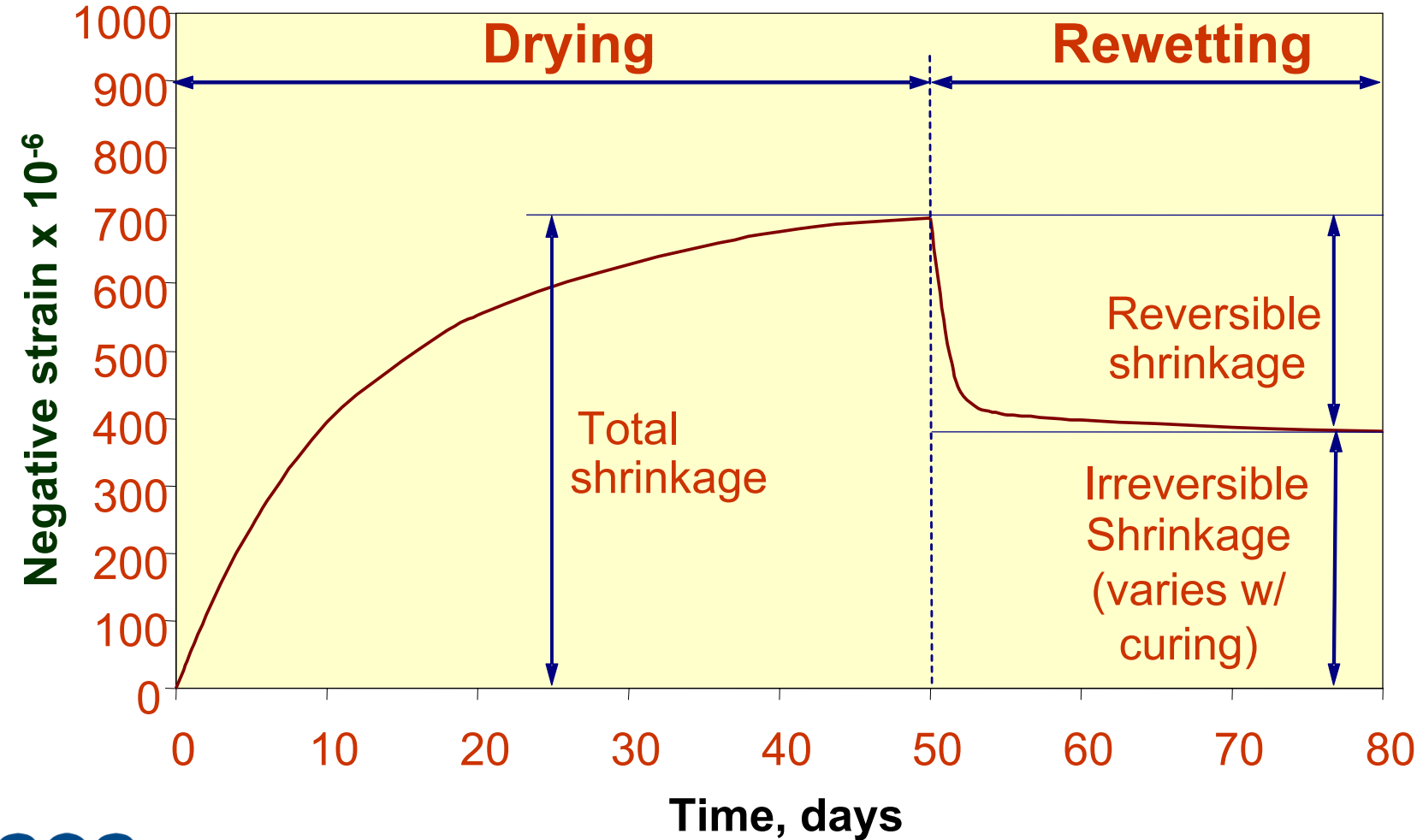




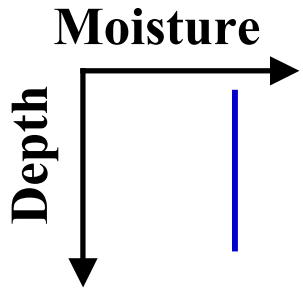




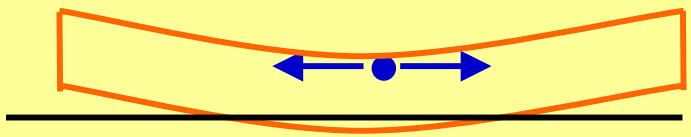
Typical Concrete Drying and Rewetting

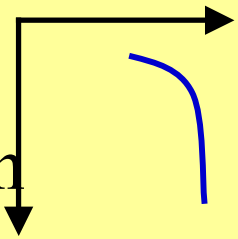


Moisture Gradients

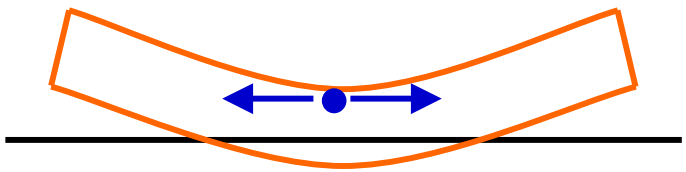


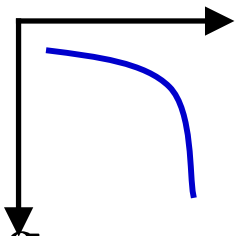
Just after placement – flat slab, No gradient





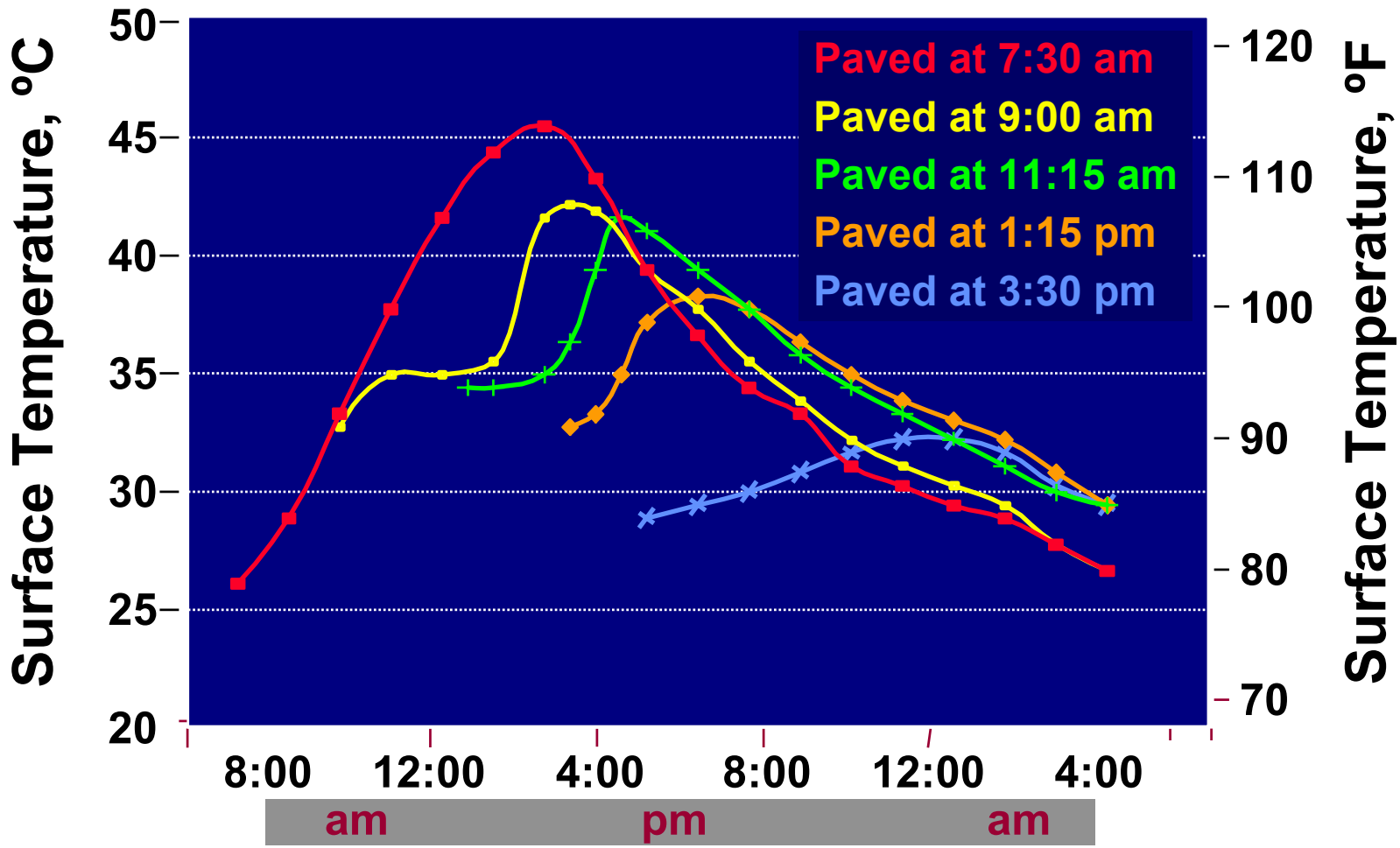
Over time, some surface shrinkage occurs with good curing



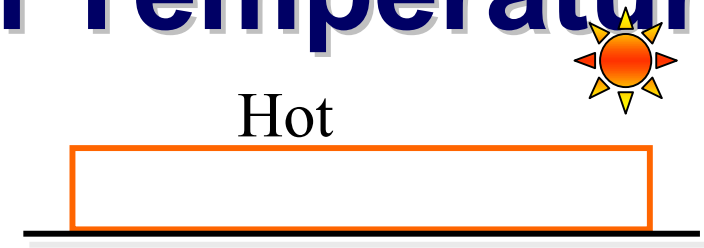


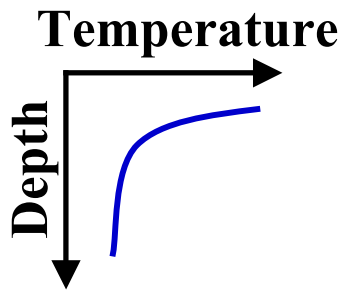
Higher surface shrinkage occurs with poor curing

PCC Temperature for Different Paving Times (Sunny Days)

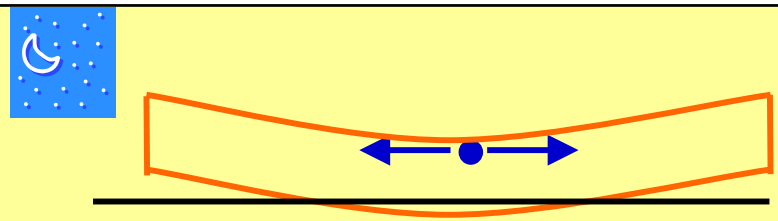


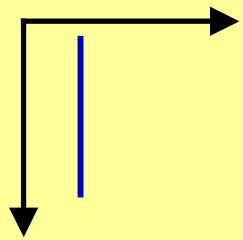
Built-in Temperature Gradient



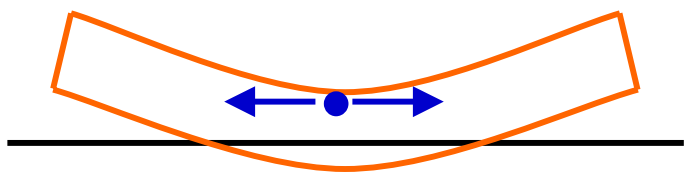


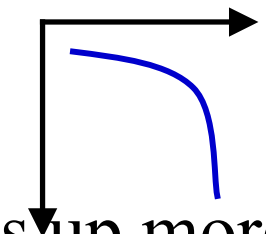
After placement–Flat slab, but positive gradient





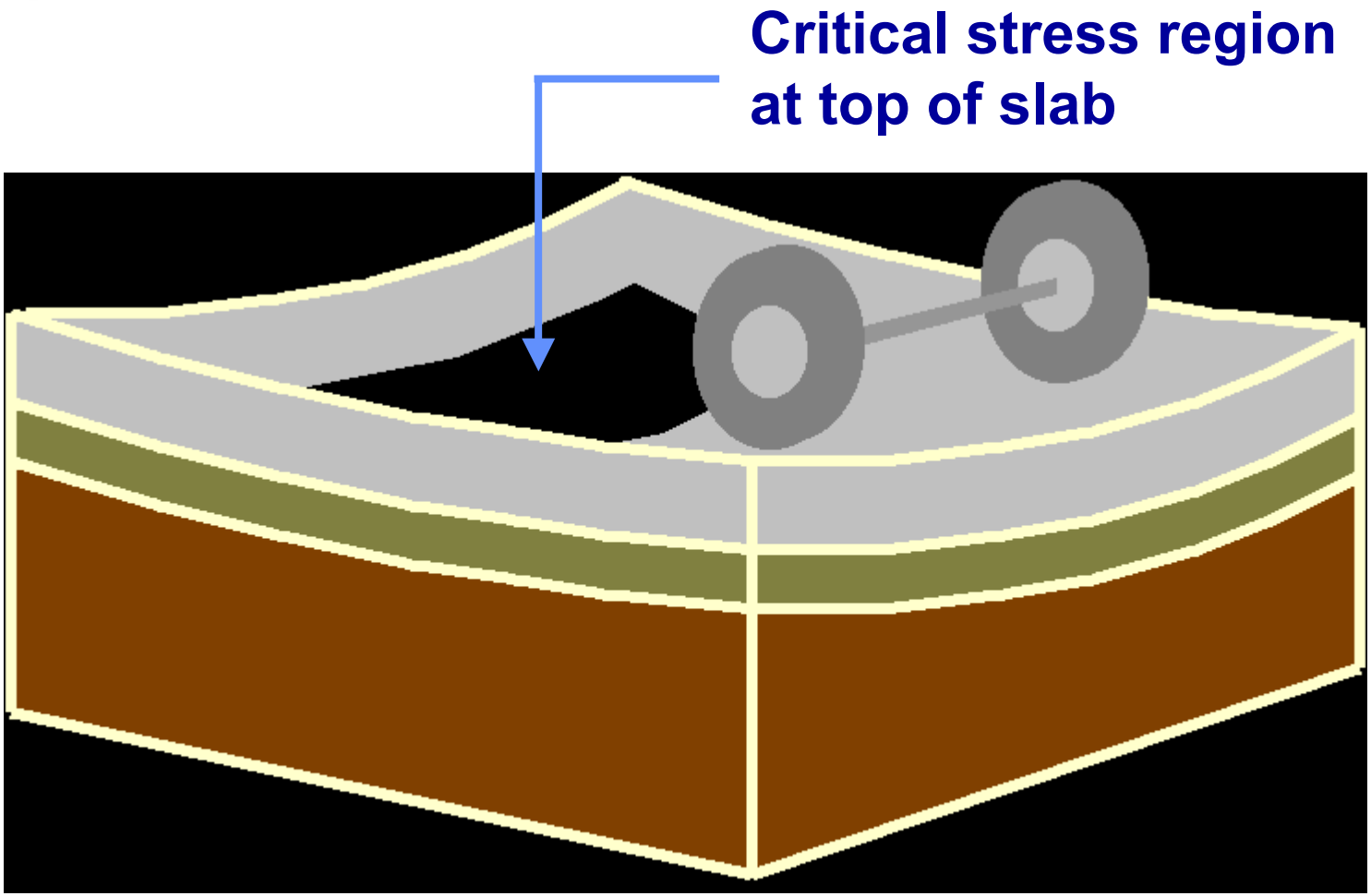
That night when zero gradient–Corner curls up!



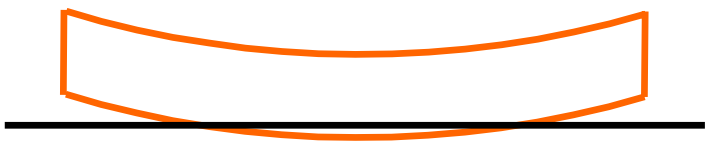
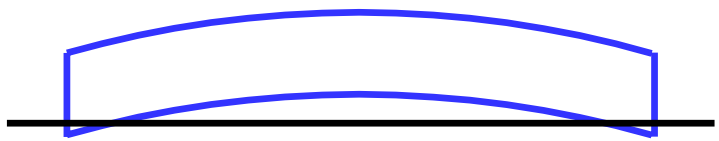


Early next morning, surface cooler–Corner curls up more!!!

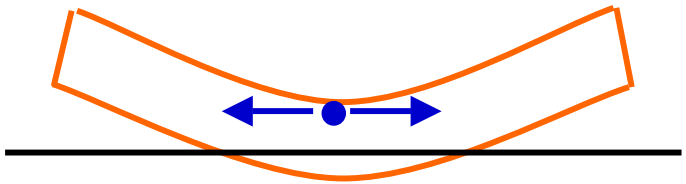
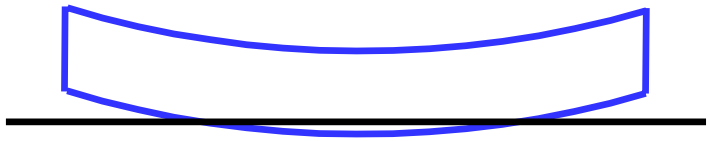
Upward Curl—Top Down Crack



Construction Temperature Effects

Compare two sections with same slab length of 15 feet, undoweled Sections are built in very different climatic conditions	
Minnesota (thickness = 8”)	Arizona (thickness = 13”)
Paved at 8 AM August 1997 	Paved 12 midnight August 1997 
Set at 1 PM with high curl up 	Set at 5 AM with slight curl down 

Construction Temperature Effects

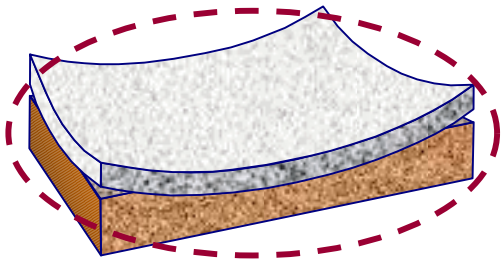
Minnesota (thickness = 8”)	Arizona (thickness = 13”)
After shrinkage and creep: Built-in gradient of -4.7 degF/in 	After shrinkage and creep: Built-in gradient of -2 degF/in 
Higher locked-in gradient in Minnesota as a result of high built-in temperature gradient	Lower locked-in gradient in Arizona as a result of reversed built-in temperature gradient
This slab may develop top down cracks over time	Unfavorable weather (heat, solar radiation) in Arizona overcome by selecting proper paving time

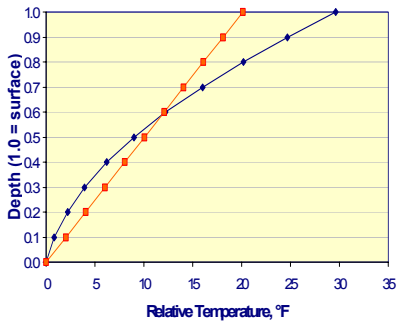
Permanent Curl/Warp

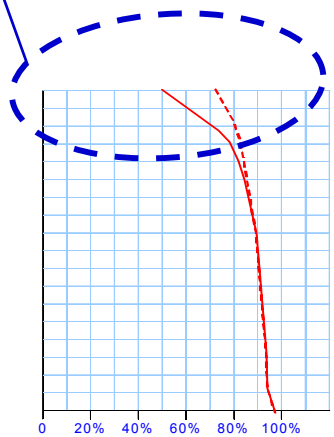
- Total permanent curling/warping includes following:
  - Built-in temperature gradient (upward saucer curling that is permanent)
  - Irreversible shrinkage of surface (upward saucer warping that is permanent)
- NCHRP 1-37A found that average curl/warp results was about -10 degrees F through depth of slab. This is approximately -1 degree F per inch of slab.

Components of Curl-Warp Stresses in Slab during Service

Gradient in top 1-2 in







Built-in Permanent Curling and Warping

Actual Temperature Gradient-varies houly

Actual Moisture Gradient-varies w/humidity

$$\Delta T = \Delta T_{Built-in} + \Delta T_{Actual} + \Delta T_{Moisure}$$

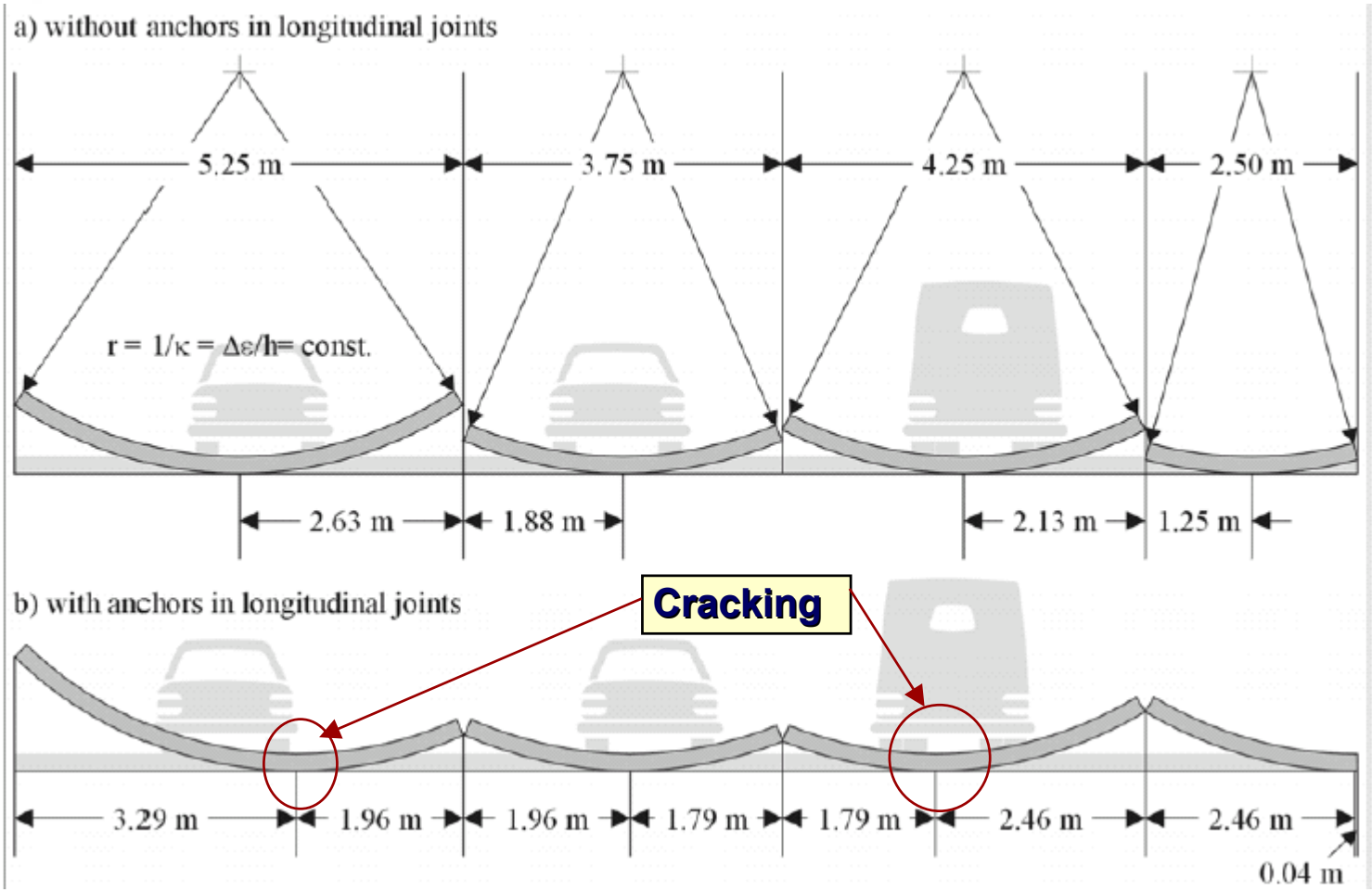
Reduce the built-in factor through good curing choices

Research from Techical University of Munich

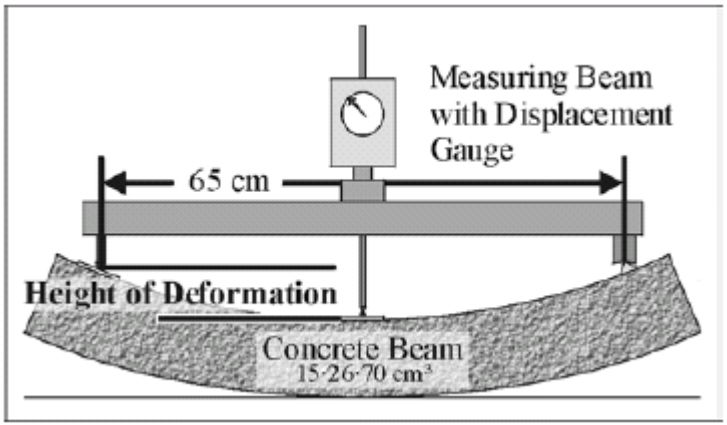
- **"The Influence of the Curing Method on Early Cracking Risk During Hot Weather Paving"**
- Hiller and Springenschmid

  9th International Symposium on Concrete Roads, Istanbul, Turkey, April 2004

Effect of Slab Length and Load Transfer



Hiller and Springenschmid, 2004



Measurement of Curl (28-in)

Foil: transparent plastic foil(not protect from solar Radiation)

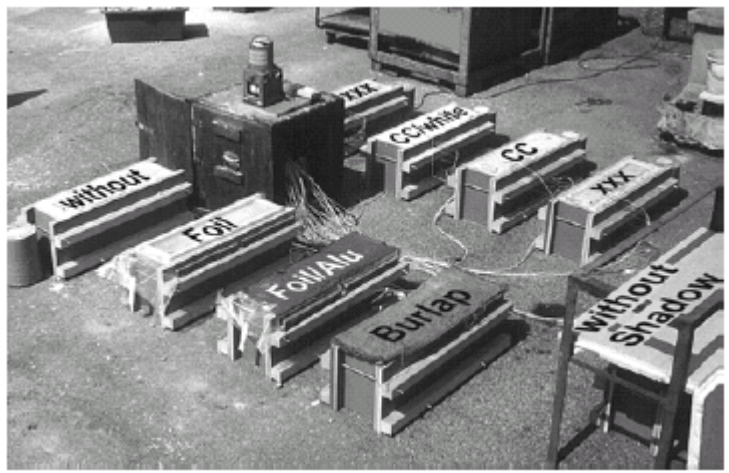
Foil/Alum: Aluminum coated plastic foil

CC: a sprayed transparent curing agent

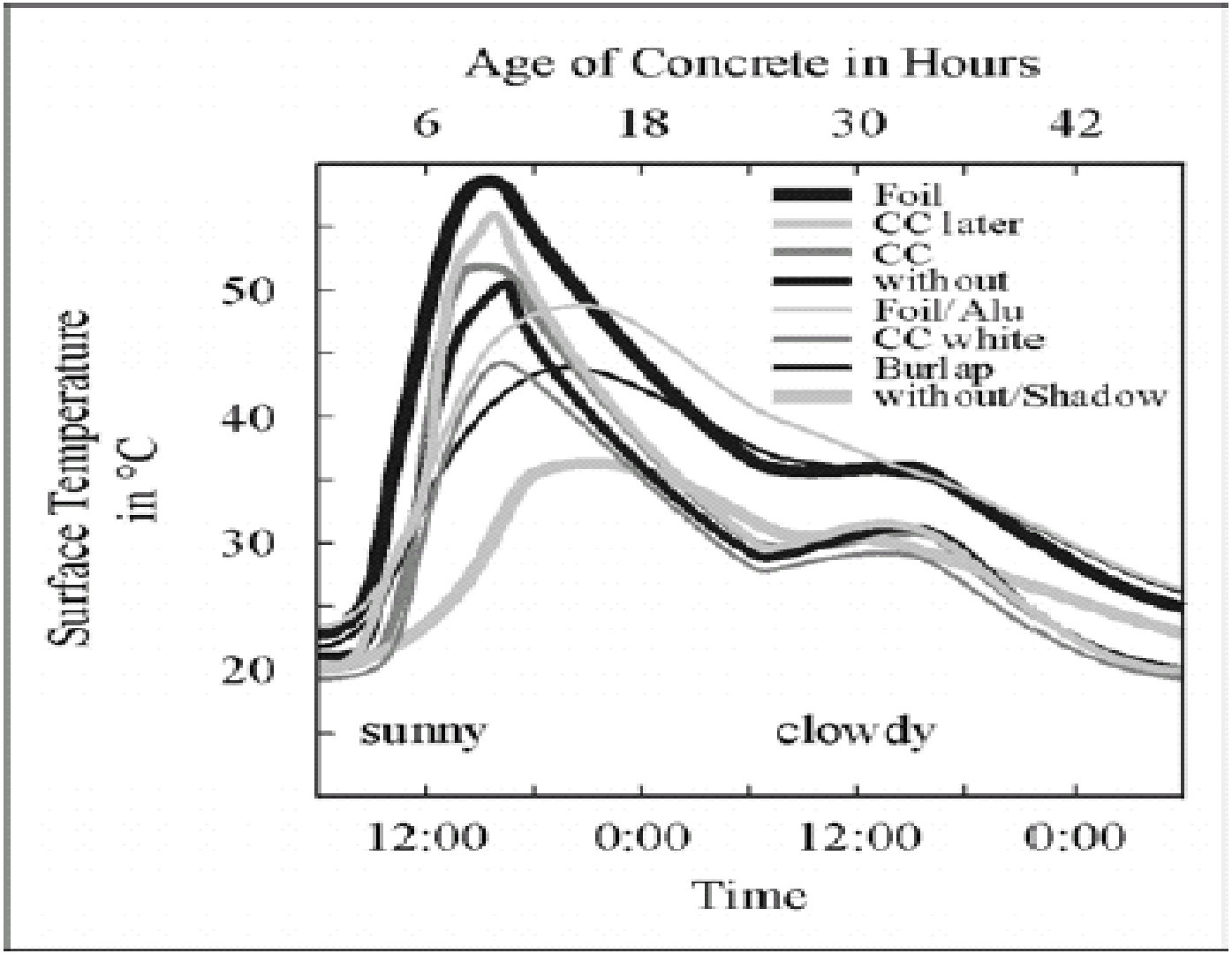
CC White: reflecting (white) curing agent

Burlap: moist burlap laid on top

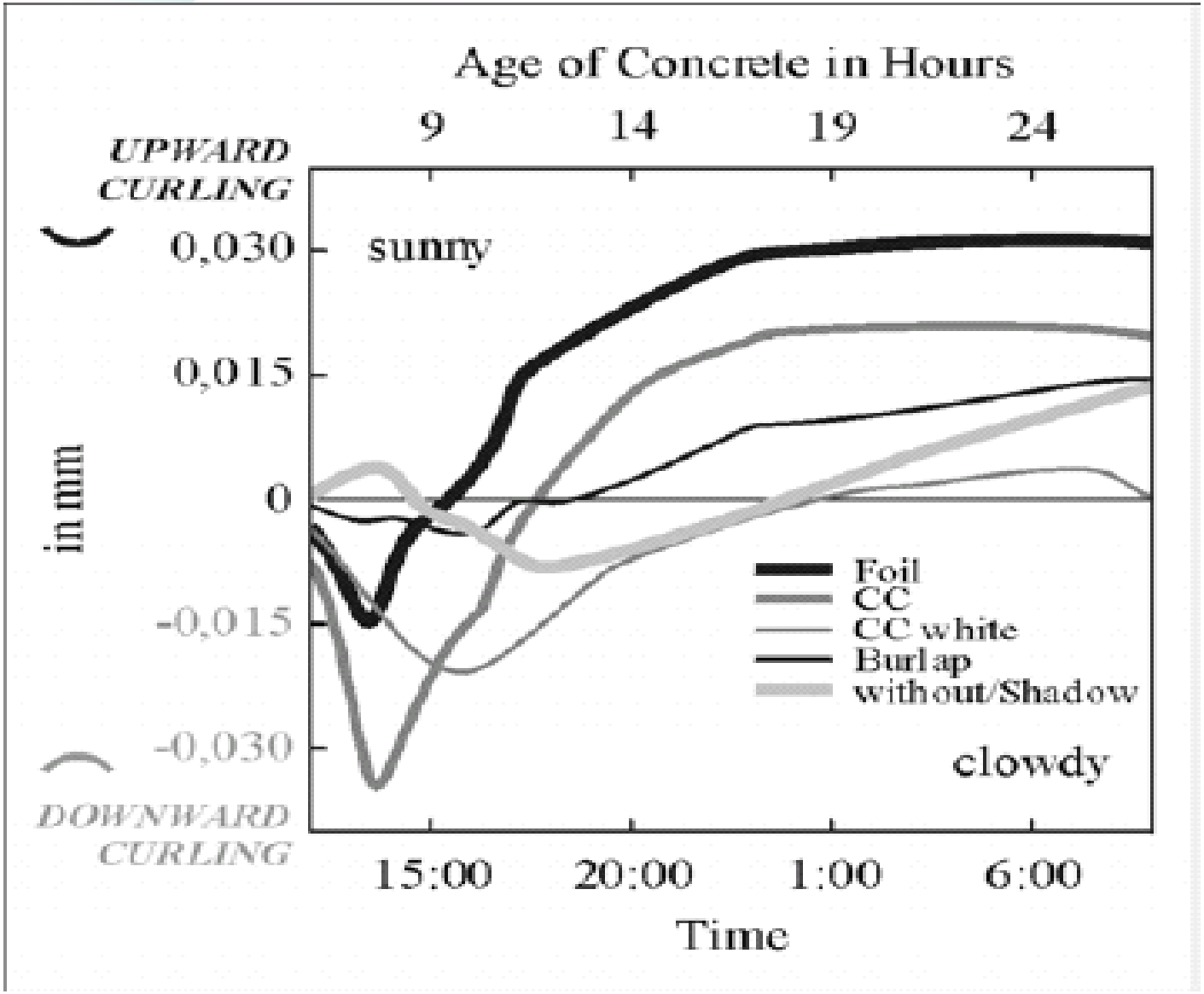
Without CC/In Shadow: untreated surface with a sprayed water film, located in shadow (no solar radiation)



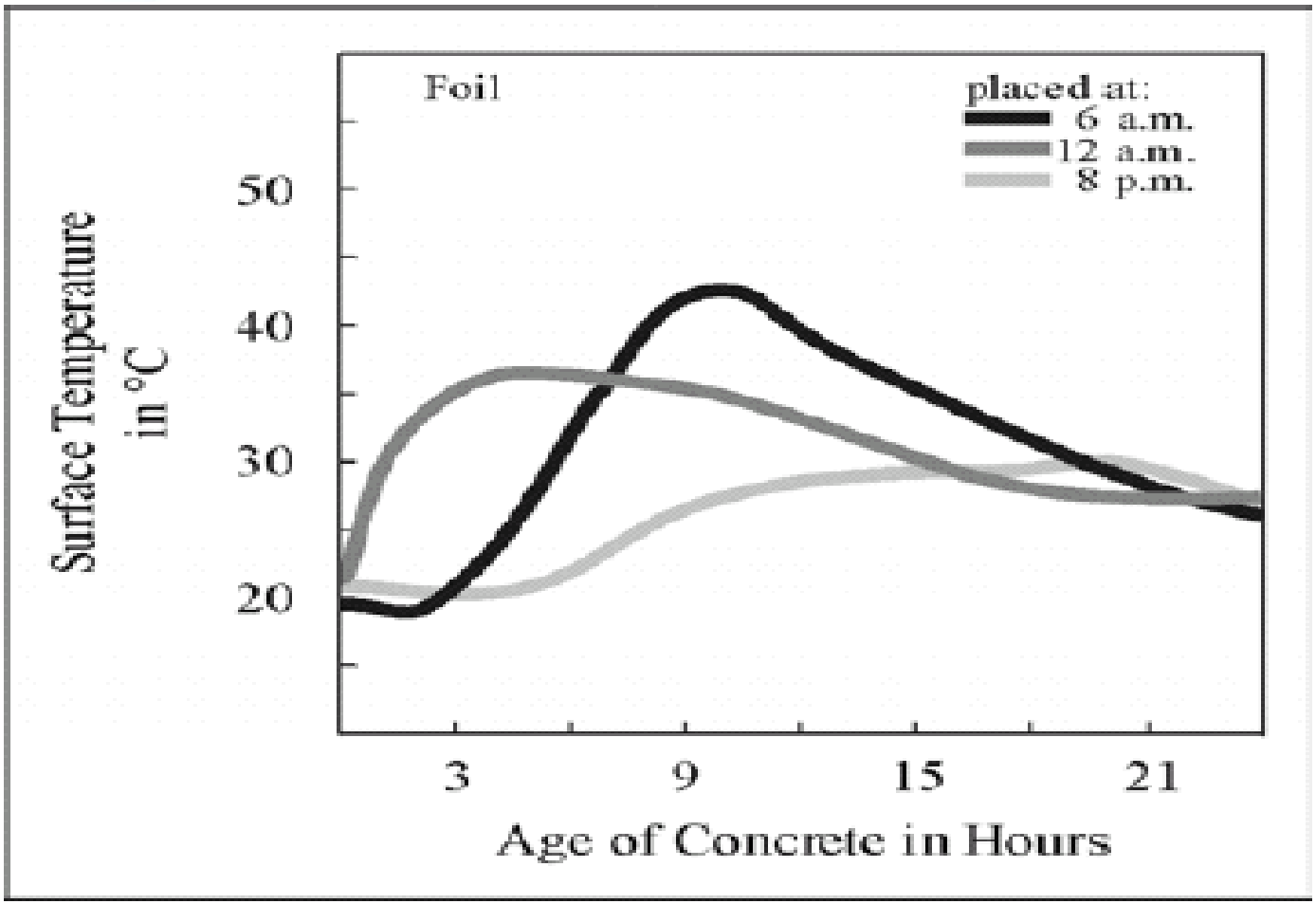
Varying Curing Methods & Times of Day Placement



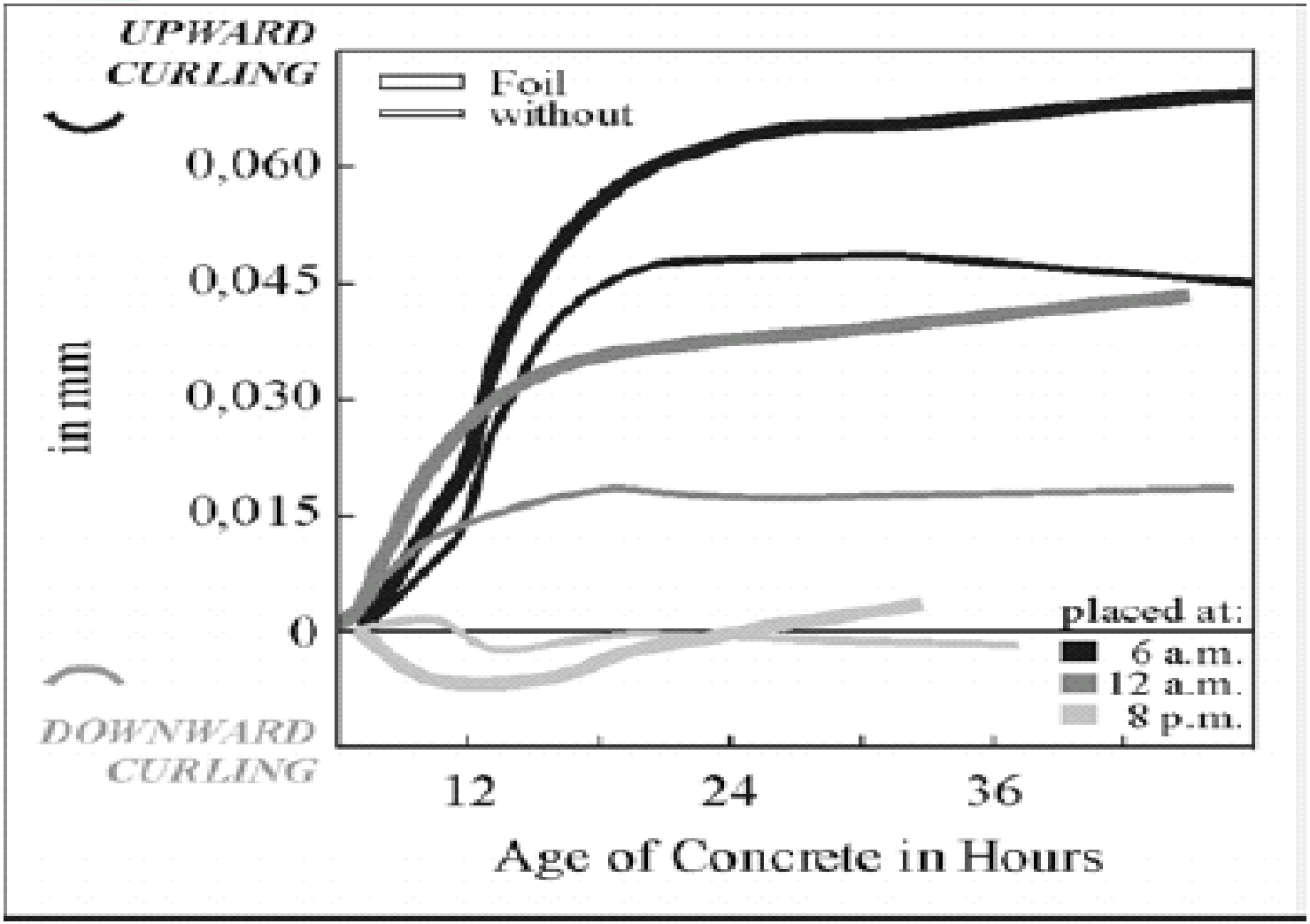
Development of surface temperature placed at 6 am & subjected to various curing methods



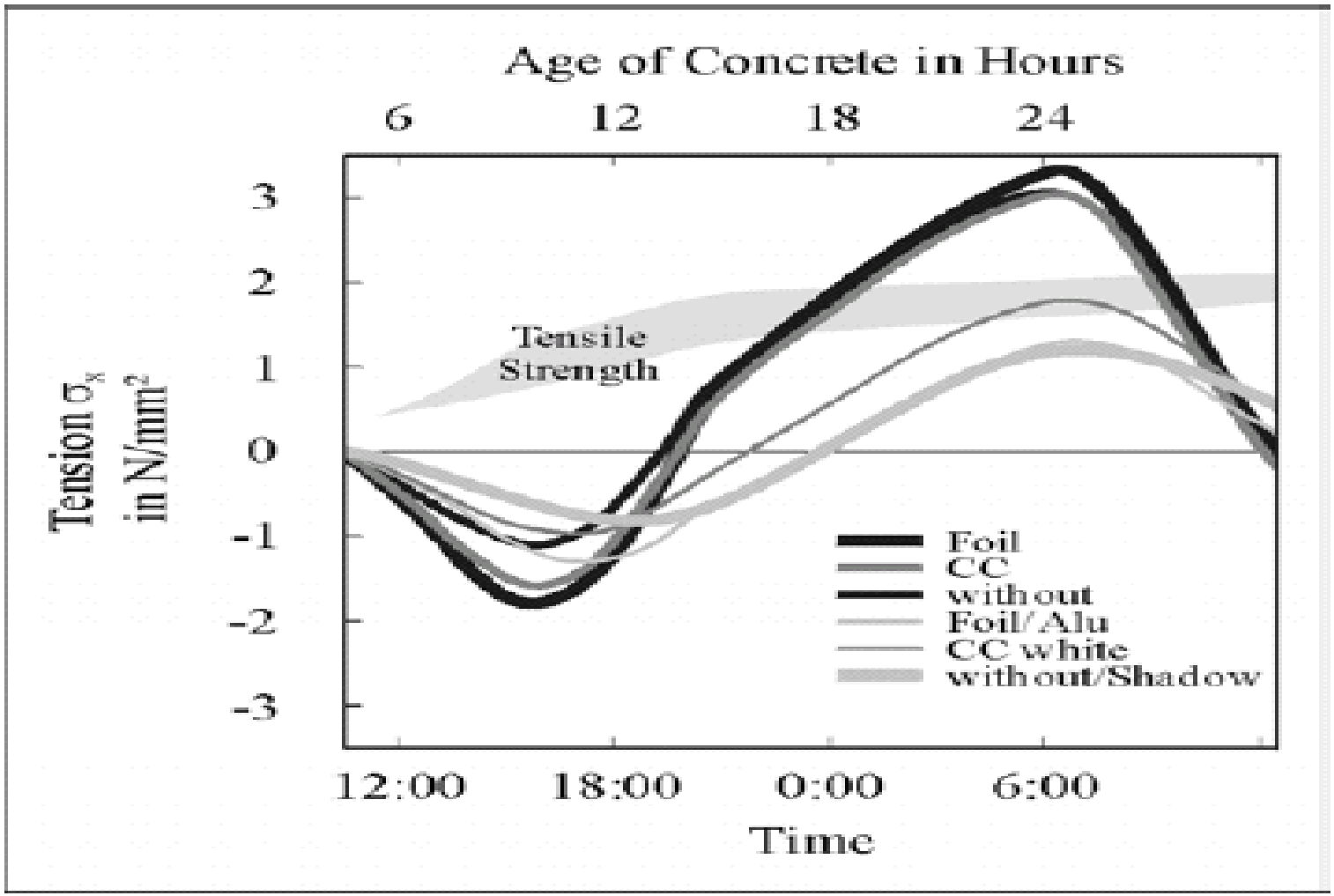
Curling of cured PCC beams, cast at 6:00am



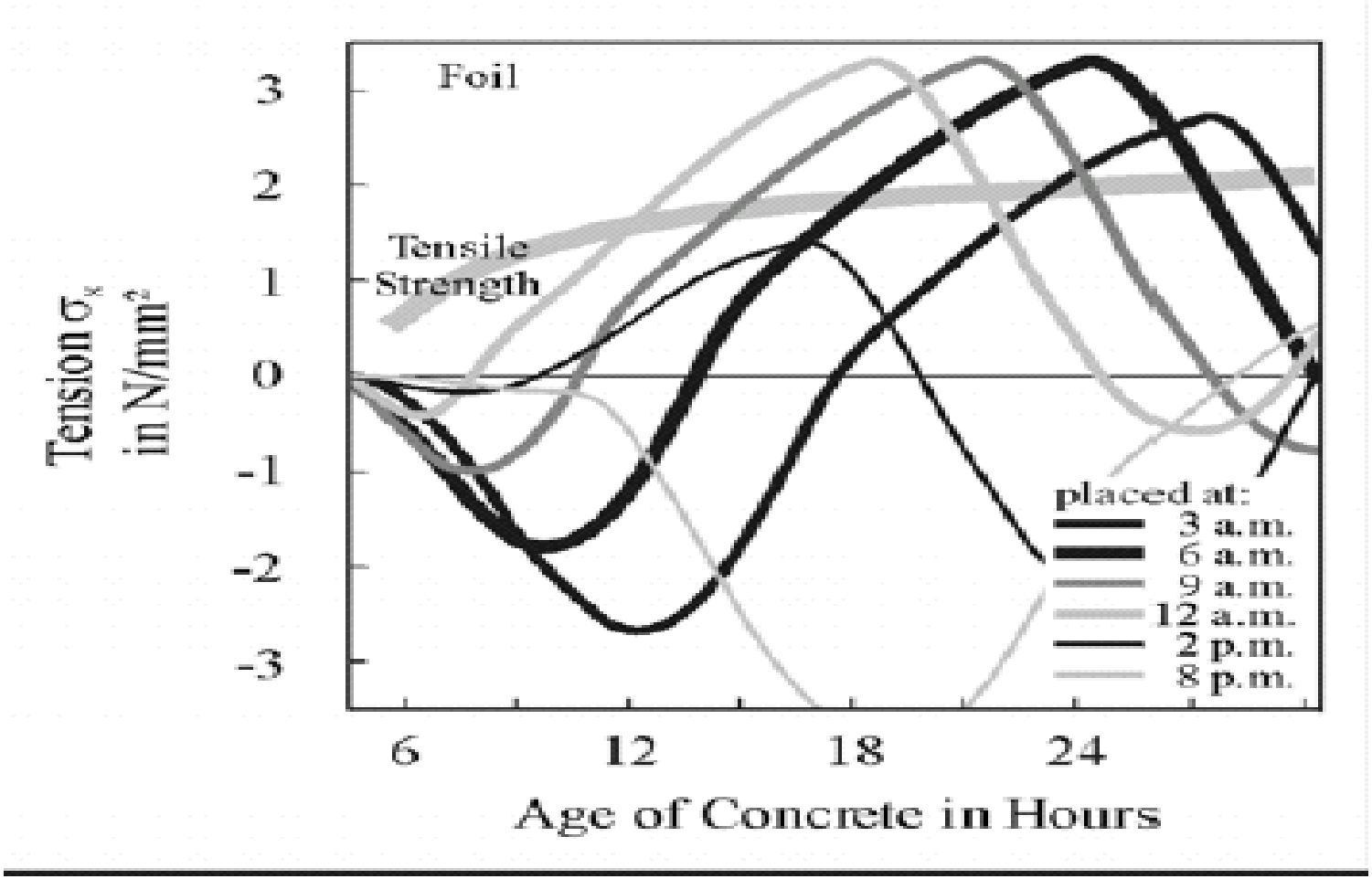
Surface temperature of beams placed at different times



Curling of beams placed at different times



Stress of surface of concrete slabs cured differently



Stress of surface of concrete slabs placed different times

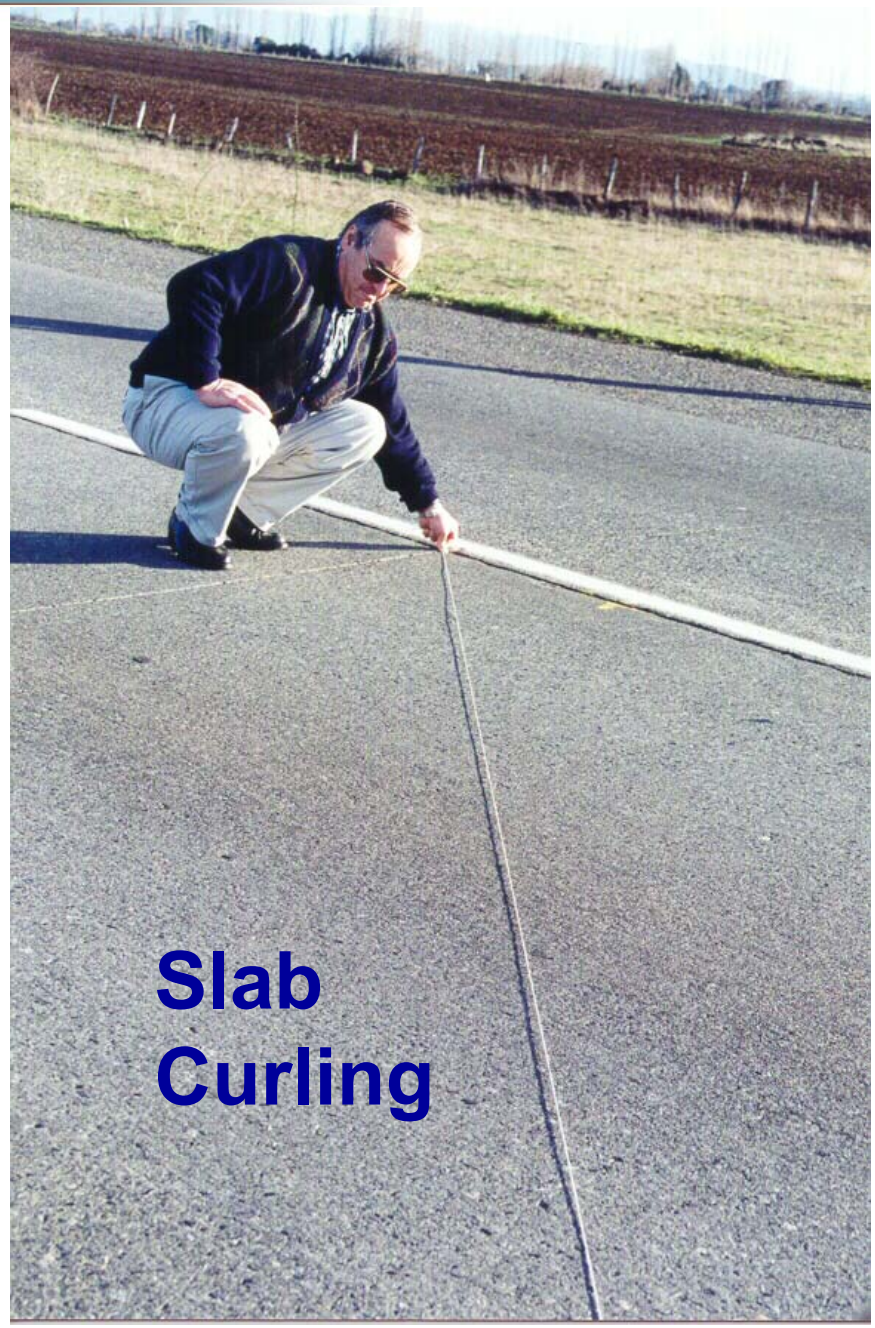
Hot Weather Curing of Concrete Pavements—Summary

1. **Curing has major effect on loss of moisture from new concrete surface and risk of plastic shrinkage cracking**
   - Greatly needed for hydration & strength gain of surface (critical location for pavement!)
   - Curing practices needed very quickly after placement
   - More evaporation in early stages results in more shrinkage, and thus, cracking potential
   - **RECOMMENDATION: protect from solar radiation by means of white curing compound, and, in severe hot conditions, by late afternoon or nighttime placement (water spray on surface also helpful).**

Hot Weather Curing of Concrete Pavements—Summary

2. **Curing also has a major effect on built-in permanent temperature and moisture gradients and slab top down cracking risk.**
   - PCC surface temperature during first hours of hardening is critical for the magnitude of thermal stresses of the hardened concrete and the related top down cracking risk.
   - Pavement placed in morning on sunny day will develop a high surface temperature and a high thermal gradient through the slab causing high top tensile stresses and potential cracking.
   - **RECOMMENDATION: protect from solar radiation by means of white curing compound, and, in severe hot conditions, by late afternoon or nighttime placement (water spray is placed on surface).**

Avoid excessive built-in curling



Thank you

Acknowledgement

Some slides and pictures from ACPA

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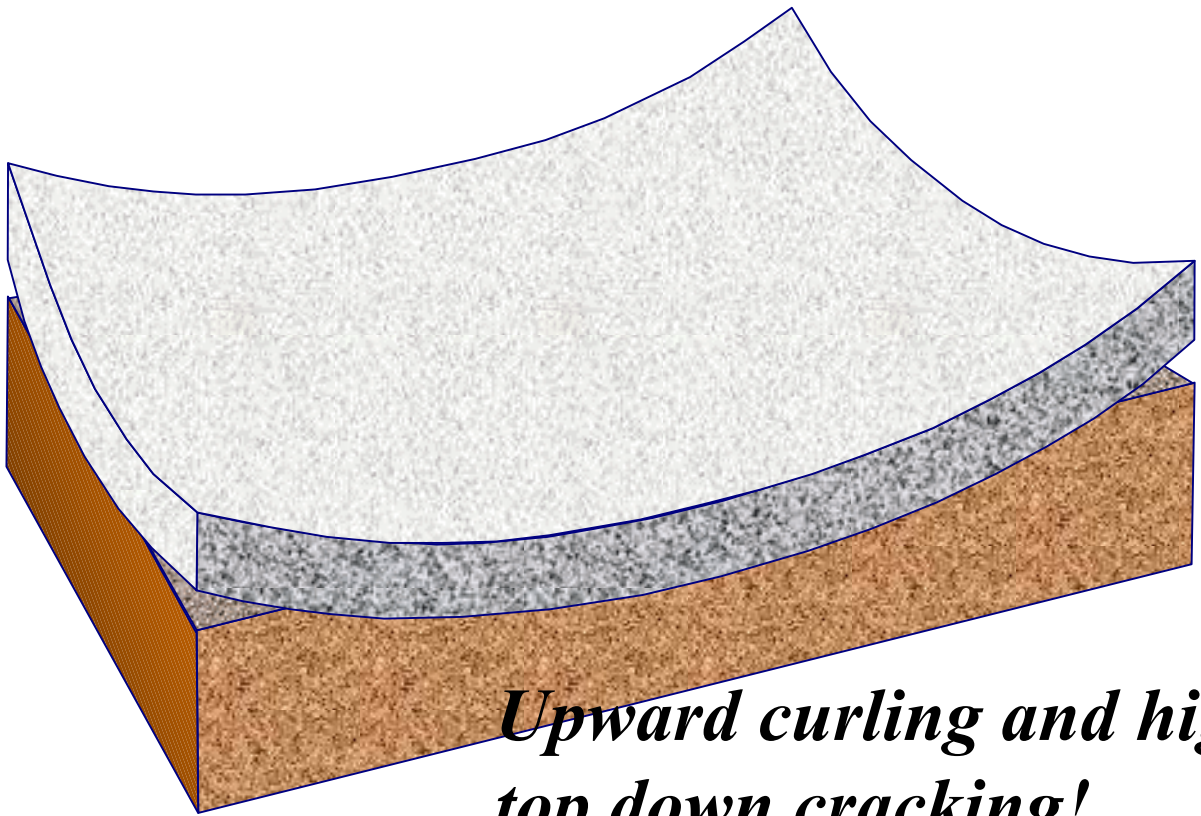
Avoid this Result!!!



Upward curling and high risk of top down cracking!

Curing of Concrete Pavements—Reduce top-down cracking risk

Reduce "built-in" upward curling and high early shrinkage.

- Use highly reflective curing compound.
- Spray water in severe conditions to cool surface.
- Severely hot weather: alter placement time to between 2 pm (afternoon) to 2 am.

Findings 1

- Tensile stresses can be avoided at the top side surface by:
  - protection from solar radiation by means of white curing compounds, and/or by late afternoon or nighttime placement.
  - Protection from loss in moisture content by means of white curing compounds.
- The choice of concrete placement time shows to have a decisive effect on the stress development.

Findings 2

- Temperature induced cracking (at surface) in summer paving can be avoided, apart from the on time cutting of joints, by the application of the correct curing process, which provides a sufficient protection from heating, especially from solar radiation.
- Curing measures have to protect from a loss of moisture, in order to prevent a drying induced crack formation at the top surface (plastic shrinkage cracking).

Findings 3

- Reflecting curing agents: reflecting curing agents or soaked burlap reduce the surface temperature and prevent a moisture loss at the same time.
- In case of high temperatures, besides spraying of a curing agent, additional spraying of water is recommended to cool surface and prevent moisture loss.
- Also, in hot summer times, adjust time of paving to between 2 pm and 2 am if possible.

Findings 4

- In hot summer paving, pavements are sprayed with reflecting curing agents and additionally cured with sprayed water to account for the strong effect of solar radiation and heat of hydration coinciding at the same time.
- This will greatly reduce top down cracking of concrete pavements.